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# PROCESS DEVELOPMENT FOR AUTOMATED SOLAR CELL AND MODULE PRODUCTION

## TASK 4: AUTOMATED ARRAY ASSEMBLY

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## ABSTRACT

The Automated Lamination Station is mechanically complete and is currently undergoing final wiring. The high current driver and isolation boards have been completed and installed, and the main interface board is under construction. The automated vacuum chamber has had a minor redesign to increase stiffness and improve the cover open/close mechanism.

Design of the Final Assembly Station has been completed and construction is underway.

## 1.0 INTRODUCTION

The mechanical construction (i.e. machine shop work and physical assembly) of the Automated Lamination Station is complete. We are currently in the phase of final wiring prior to the first full operational tests.

Individual tests of all the pneumatic and electrical components have been performed resulting in the resizing of some of them.

The Automated Vacuum Chamber has undergone a minor redesign to improve the stiffness of the chamber and to make the chamber opening/closing mechanism more positive in its action.

Progress with the interface electronics involve the high current driver and optical isolator boards which have been completed and installed in the control cabinet. The main computer interface board is essentially complete requiring only the multiplexer (which connect the various temperature and vacuum sensors to the single A to D convertor) to be finished. The cables connecting the control cabinet with the laminating station and vacuum chamber (one for power to their various functions and another for feedback signals) have been fabricated.

Work on the Final Assembly Station (which takes the completed module from the vacuum chamber, applies the edge seal and places the module in a GRC panel) has begun. The basic design is complete and the detailing and construction about half finished.

## 2.0 TECHNICAL DISCUSSION

### 2.1 Lamination Station

As stated in previous reports, The Lamination Station (Figure 1) represents the bulk of the program. The following discussion is broken up into the various areas of the machine. Preceding that, however, is a description of the machine's operation cycle.

#### 2.1.1 Operation Sequence

The general sequence of operations that must be performed by this station is as follows:

- 1) Place the bottom lamination materials in the lamination chamber.
- 2) Place the interconnected circuit of cells in the chamber (done by robot).
- 3) Place the top lamination materials into the chamber.
- 4) Place the cover glass (done by robot).
- 5) Release the chamber to begin vacuum/thermal cycling and wait for a new chamber to come into place.

The intent of this contract is to use the JPL supplied Unimate 2000 robot in the lamination process. However, we have kept the design flexible enough that steps 2) and 4) above (and their counterparts in the detailed description below) could be done by a simple transfer arm or even manually.

The detailed sequence for the preparation station's functions is as follows:

- 1) A chamber is inserted into the station and the cover is rolled back.
- 2) The feed rollers feed the bottom lamina sheet through the shear into the shuttle which is already parked at that end of the framework.

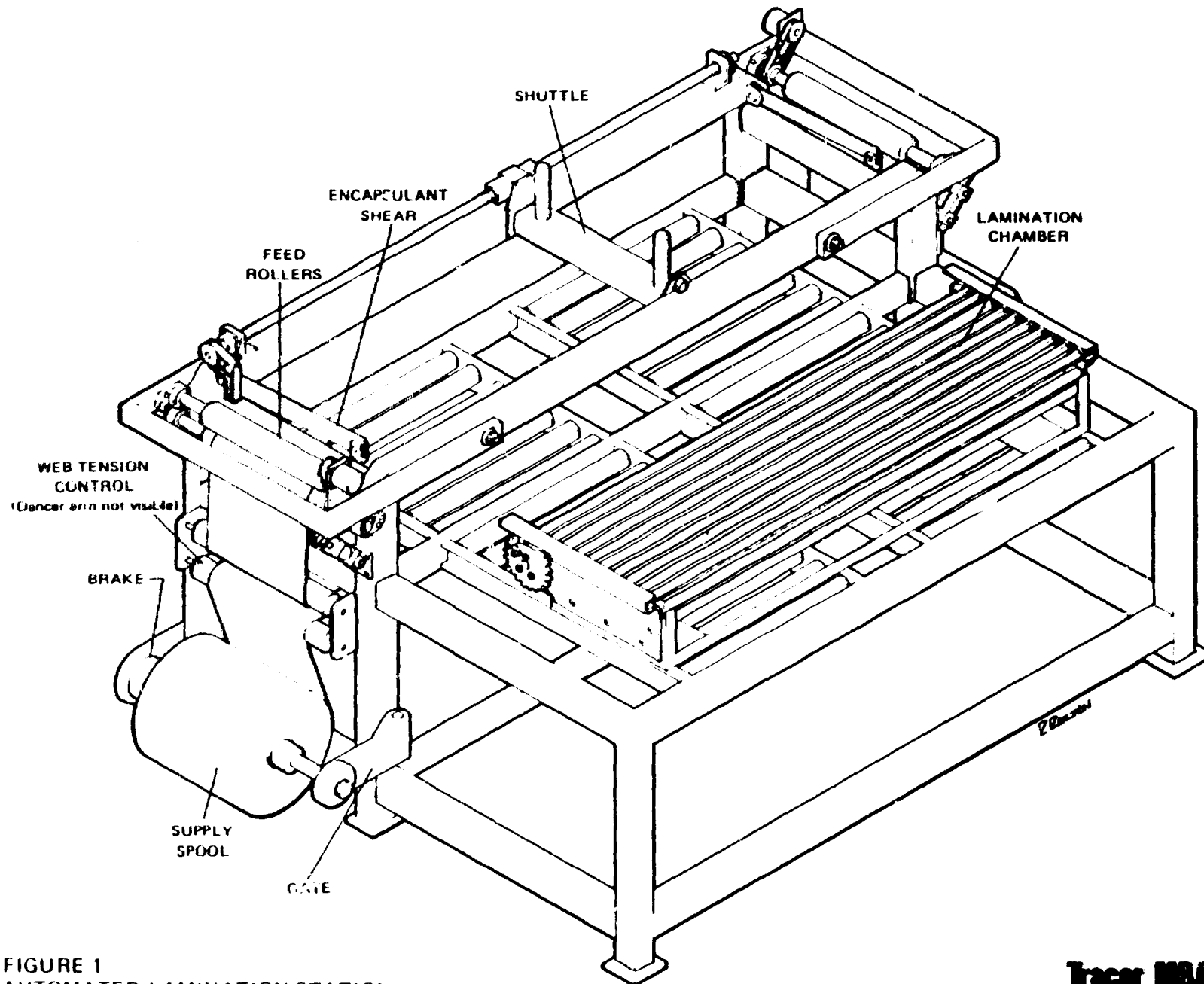


FIGURE 1  
AUTOMATED LAMINATION STATION



- 3) The shuttle clamps onto the end of the material.
- 4) The feed rollers disengage.
- 5) The shuttle pulls the correct length of bottom lamina (in our case 48") out over the chamber.
- 6) The feed rollers re-engage to prevent the material from "snapping back" through the feed path after cutting (which it would since the dancer arm puts the material under tension).
- 7) The shear cuts the material off.
- 8) The shuttle pulls the material into its final position.
- 9) The shuttle releases the material and parks at the far end.
- 10) The interconnected cells are placed into the chamber by the robot.
- 11) The top lamina is measured out and cut in the same manner as the bottom lamina (steps 2-7) by an identical mechanism at the other end of the station.
- 12) The top lamina is positioned in the same manner as the bottom except that retractable side supports prevent the material from dragging on the cells (which could displace them from their correct position).
- 13) The top lamina is placed on top of the cells by opening the shuttle clamp and retracting the side supports.
- 14) The robot places the cover glass into the chamber.
- 15) The chamber cover is rolled closed, the chamber is ejected for vacuum/thermal cycling and a new chamber comes into place.

### 2.1.2 Description and Progress

Figure 2 shows the Lamination Station in its present (and hopefully final) configuration. This, combined with the artist's rendering (Figure 1) shows the location of all the components about to be discussed.

#### 2.1.2.1 Shuttle

This moving clamp draws the encapsulant material from the feed rolls at either end and out over the chamber. It consists of a rectangular section body with a pneumatically operated clamp underneath. Flared surfaces guide the encapsulated material into the clamp. The shuttle is driven via a ball screw on one side and is free riding on needle bearing rollers on the other.

The shuttle clamp was connected to an air supply to check its operation. Although it did operate smoothly without binding, the action was somewhat sluggish. This was traced to solenoid valves which were too small. They were replaced with larger orifice valves.

The first operations of the shuttle drive motor showed that it, too, was undersized. Although adequate to move the empty shuttle or to pull the material with no applied tension, the motor would stall if even a slight tension was applied to the material. The motor has been replaced with a larger one with triple the torque. Its larger casing, however, has required that the motor be mounted in a location different than shown in the illustrations.

#### 2.1.2.2 Feed Rollers

At either end of the machine are a set of pinch rollers whose job it is to feed encapsulant material from the supply roll into the shuttle. After the material is fed (about 6") the rollers must separate to allow the material to be pulled through them unobstructed. This is achieved by mounting the top roller (and also the drive motor) on a square U shaped pivot arm. The arm is raised and lowered by means of an air cylinder. We decided to fabricate the rollers in-house, rather than buying them off-the-shelf as with the conveyor and dancer rollers described below. This was done in order to maintain

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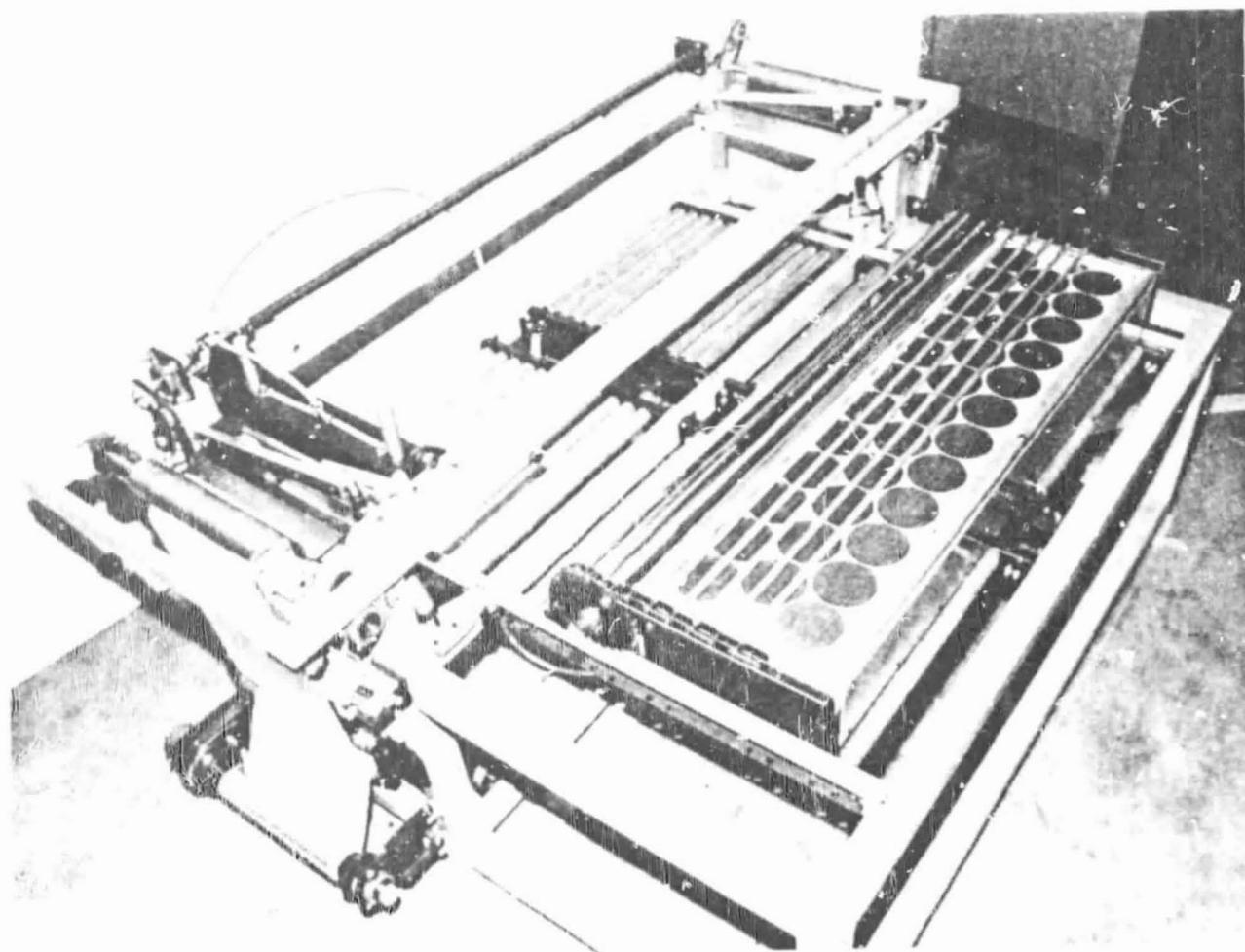


FIGURE 2  
AUTOMATED LAMINATION STATION

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the extremely close tolerances necessary to assure that the rollers run true which will prevent the encapsulant from wandering as it is fed. After being installed and aligned, the rollers run with only a 0.001" gap along their entire 18" length. The bearing mounts were drilled and pinned to maintain this alignment in the event of future disassembly.

In testing, the motors that drive the feed rollers were also found to have only marginally adequate torque. These were replaced with the next larger size (actually the old shuttle drive motor) to insure performance.

In contrast, the valves and cylinders that operate the pivot arm were somewhat overdesigned. Right from the start they have been able to open and close the rollers with considerable authority.

#### 2.1.2.3      Encapsulant Shears

To cut the encapsulant materials after they have been pulled by the shuttle, there is a shear located at both ends of the machine. Each of these consists of a fixed bottom knife bar and a moving upper knife bar (Figure 3). They are made of aluminum with the actual cutting surfaces made of hardened tool steel. The design is similar to the common office paper cutter although significant differences exist to adapt the concept to automated operation. If one were to look at a paper cutter, you would see that the moving blade is spring loaded to hold it tightly against the fixed blade. Also, both blades are beveled slightly (about  $10^0$ ) from horizontal to insure a sharp point of contact. These features have been retained in our design. Looking again at the paper cutter, however, reveals that the blade is long and curved. This serves two functions. First, it allows the blades to contact along a moving point rather than all at once in a line. Second, it increases the stroke to allow the long stroke/low force human actuator to cut accurately. This had to be changed in our design as space restrictions dictated a short stroke (only a  $10^0$  rotation of the moving blade). This is no problem as pneumatic cylinders can generate much more controlled force than a human arm in a short distance. The moving-point-of-contact is accomplished by careful attention to pivot points and linkage design.

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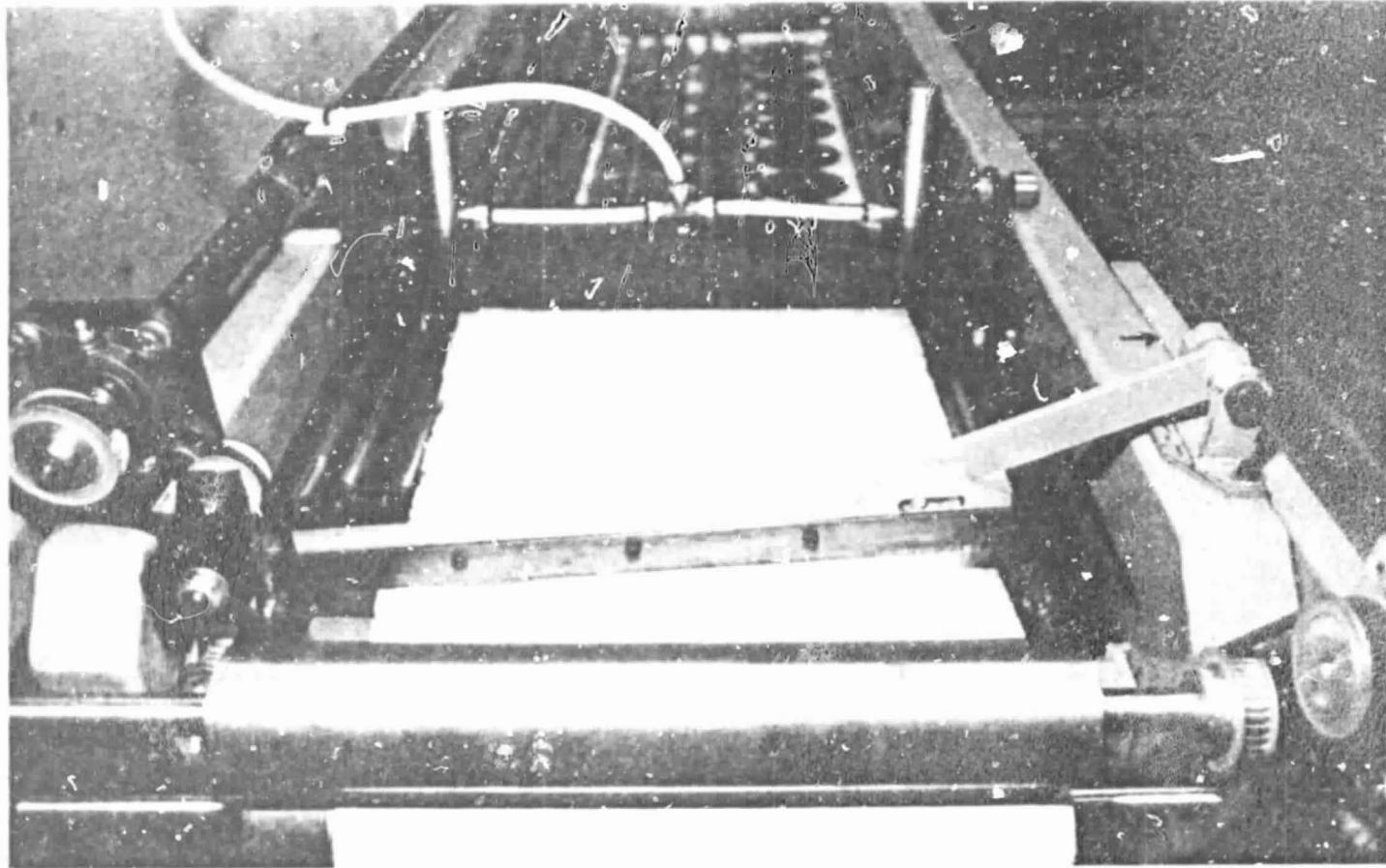


FIGURE 3  
FEED ROLLERS AND SHEAR

There is one last aspect of shear design to be addressed. Once again, looking at a paper cutter, it can be seen that the moving blade, as seen from above, must move away from the fixed blade after passing through the cutting plane to further enhance the "point contact" of the blade. It also prevents the shorn material from binding before the cut is completed. This action can also be seen in a common pair of scissors. We are accomplishing this in the same manner as the paper cutter, with a cam or ramp that forces the pivot end of the moving blade away from the fixed blade progressively during the stroke. However, due to our short stroke, the ramp cannot be located right at the pivot as the ramp angle would be too severe. A short extension arm allows a more reasonable ramp angle. As you can see, the common paper cutter, despite its workaday function, is really quite a non-trivial device!

After all of the linkages and brackets had been installed and adjusted, both shears cut the encapsulant materials beautifully when connected directly to shop air. However, when first connected through the solenoid valves, the shears' action (as with the shuttle clamp) was very sluggish and would not, in fact, cut the material. This was solved, again, by replacing the small valves with ones of larger capacity. In this case a pair of high flow rate, 5 port, 4 way spool valves are being used, one for each shear. This type of valve allows the shears to be powered both ways (up as well as down) and exhausted both ways with only one valve.

The shears are truly frightening to watch when operating and, in fact, are disconnected from their air supply most of the time as a safety precaution. OSHA style guards are being fabricated as a further safety measure.

#### 2.1.2.4      Supply Spools

Both the top and bottom lamina supply spools are mounted on identical holding fixtures. The supply spool core is supported on either side by a self-centering mandrel on a common shaft. The mandrels will accept any core size from 2" to 3" ID. The shaft support on one side of the spool is fixed and the other hinged like a gate to allow the changing of spools. The fixed side has tapered roller bearings to support the weight of a full supply spool which will be cantilevered out from it during changing before

the gate is closed. The hinged side has plain ball bearings. Also mounted on this shaft is the supply spool brake whose function is described in the next section.

Figure 4 shows the sequence for changing supply spools. First, (Figure 4A), the gate must be opened. This is easily done since the shaft is not one piece but rather unscrews like a pool cue at a point about one inch in from the gate bearing. Once the gate is open (Figure 4B) the setscrew on the mandrel is loosened and the mandrel slid off the shaft. Finally, (Figure 4C), the old core is removed. Loading a new spool is just the reverse procedure followed, of course, by threading the machine.

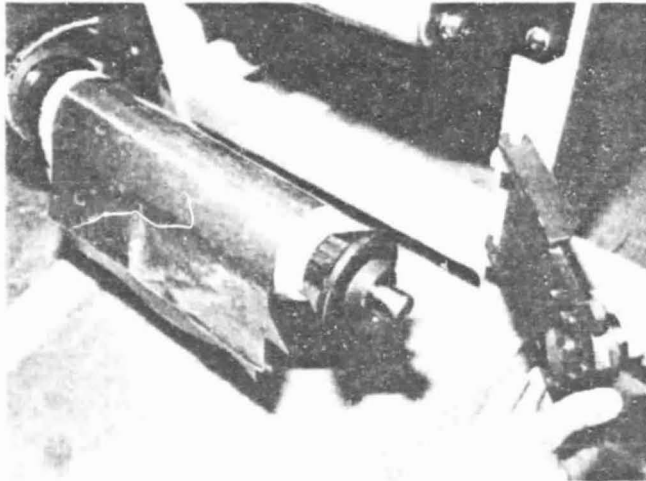
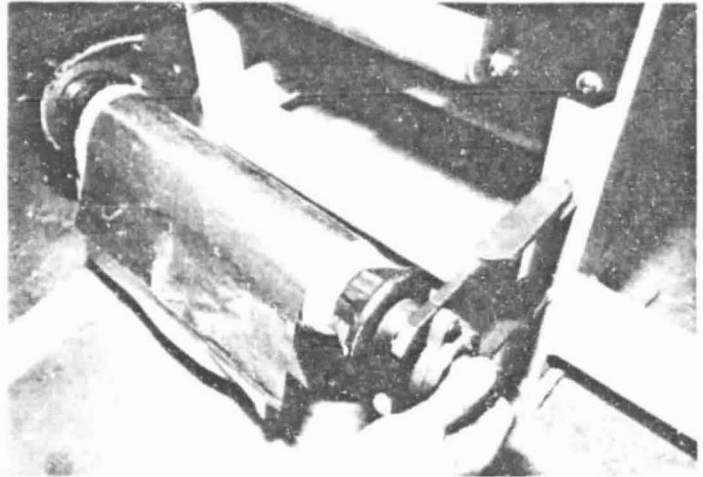
There is one aspect of the supply spools themselves that must be discussed. As stated previously, (Quarterly Report #1, Section 2.3.3) this machine requires that the supply spools be already cut to width (12" in our case) and rolled multi-ply (4 ply for the bottom lamina and 2 ply for the top). There are many machines available commercially that perform these tasks on an industrial scale but it is just not feasible for them to produce the comparatively tiny amounts that we require (a few hundred feet) to check out the operation of our machine.

To circumvent this problem, MBA has "jury-rigged" small versions of these large machines to produce the laboratory-scale quantities of material that we require.

The first of these machines (Figure 5) is called a Slitter-Rewinder. It is necessary because many manufacturers can produce materials only in standardized widths so, if they don't have an expensive commercial slitter, must sell it that way to customers. Clear EVA, for example, comes in 24 inch widths from Springborn Labs so the roll must be cut in half for our use. Due to its soft, plastic nature, the roll cannot be cut in bulk form such as on a band saw. In addition, EVA contains a release sheet (to keep it from sticking to itself) that must be slit simultaneously. Several cutting techniques were tried. Scoring (pinching between a sharp blade and a hard surface) worked well on the EVA but wouldn't cut the paper. Fixed razor blades were OK with the paper but clogged up and tore the EVA. The best solution we found was a high speed, toothless sawblade (actually an

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4A  
UNSCREW GATE  
BEARING



4B  
SWING GATE OPEN,  
UNLOCK MANDREL

4C  
REMOVE MANDREL,  
SLIDE CORE OFF SHAFT

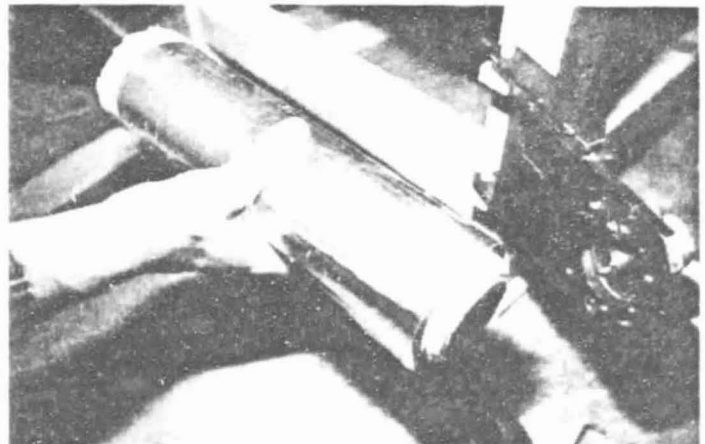
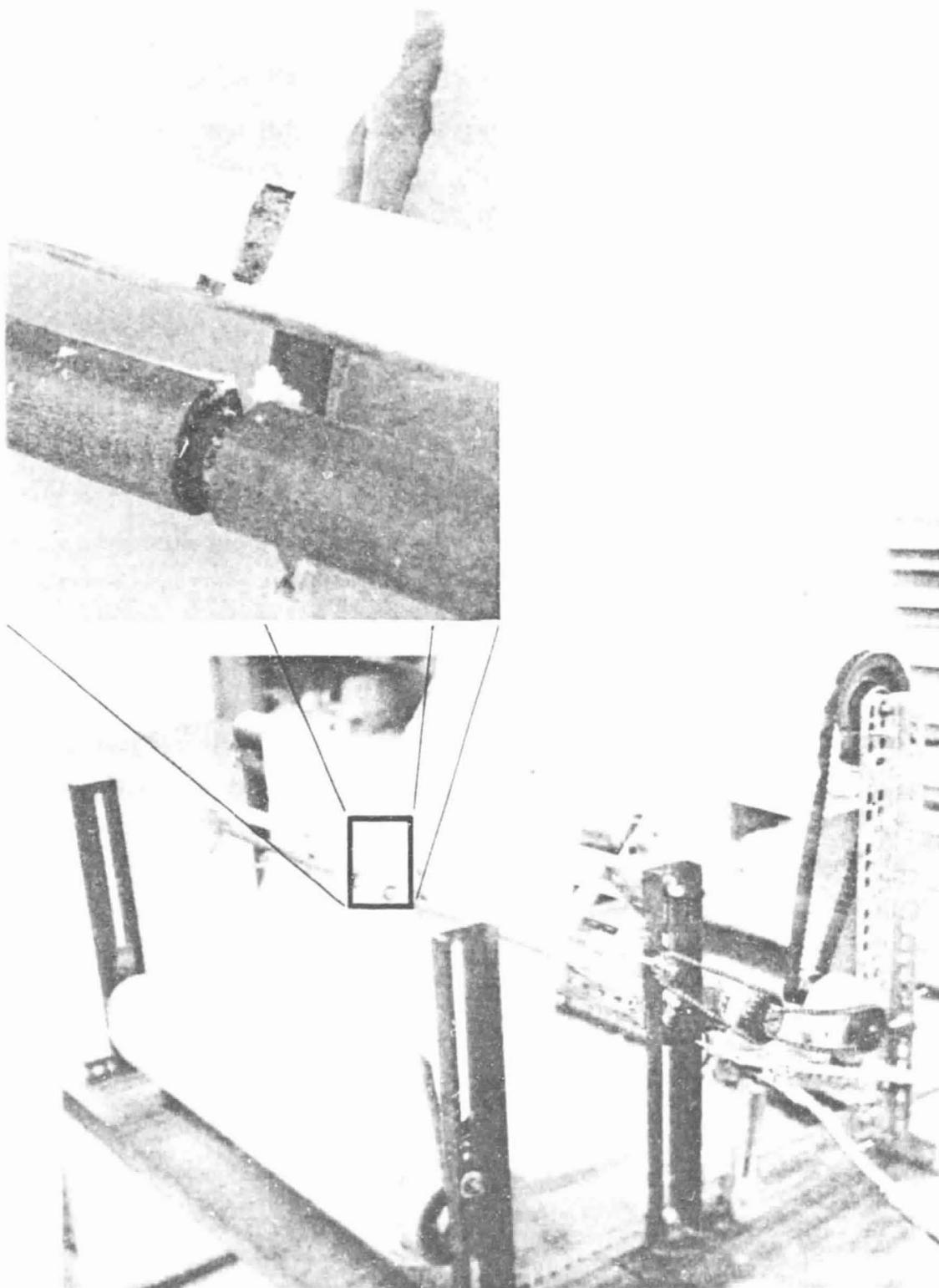


FIGURE 4  
SUPPLY SPOOL CHANGING SEQUENCE



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FIGURE 5  
SLITTER-REWINDER

adapted pizza cutting wheel!). The inset of Figure 5 shows the blade poking through the clear EVA with the release sheet beneath it. Sawdust can be seen on the lower guide bar.

The white EVA presented still another problem. Since it is not yet a commercial item, our roll was a short, experimental run. This meant that it was rolled up by hand and the release sheet consisted of dozens of individual overlapping squares of tissue. The entire roll had to be first re-rolled replacing the individual sheets with a continuous one. Also, the roll was of an odd width (32.5") which we decided to slit into thirds. This meant two passes through the slitter (there is only one blade) resulting in a white EVA roll which is slightly undersize (about 10.8").

Once all the materials are the correct width, they must be rolled together in the correct combinations to form the supply spools. Figures 6 and 7 show the multi-ply roller we have devised. Figure 6 shows the machine set up to roll the 2-ply top lamina which consists of clear EVA and Craneglas. Note the release sheet falling from the EVA (the Craneglas, incidentally, acts as the release sheet in both supply spools). Figure 7 shows the same machine re-configured to produce the 4-ply bottom lamina which consists of Mylar coated aluminum foil, Craneglas, white EVA, and Craneglas. The inset shows how the four plies come together at the bottom (the edge registration plates on the side of the spool have been removed for clarity). Since this picture was taken, a take-up spool has been installed above the EVA roll to wind up the release sheet as the EVA unwinds.

#### 2.1.2.5 Web Tension Control

In order to have good control over the lamination material (known as the web) it must be kept taut as it travels through the machine. The necessary tension is on the order of 3 lb. per inch of width (36 lb. total) for the bottom lamina and 1 lb./in. (12 lb. total) for the top. These values come from guidelines established by the thin film plastics and paper industry for their high speed machines (hundreds of feet per minute web speed). Whether they hold true for our very low speed (15 ft./min.) machine

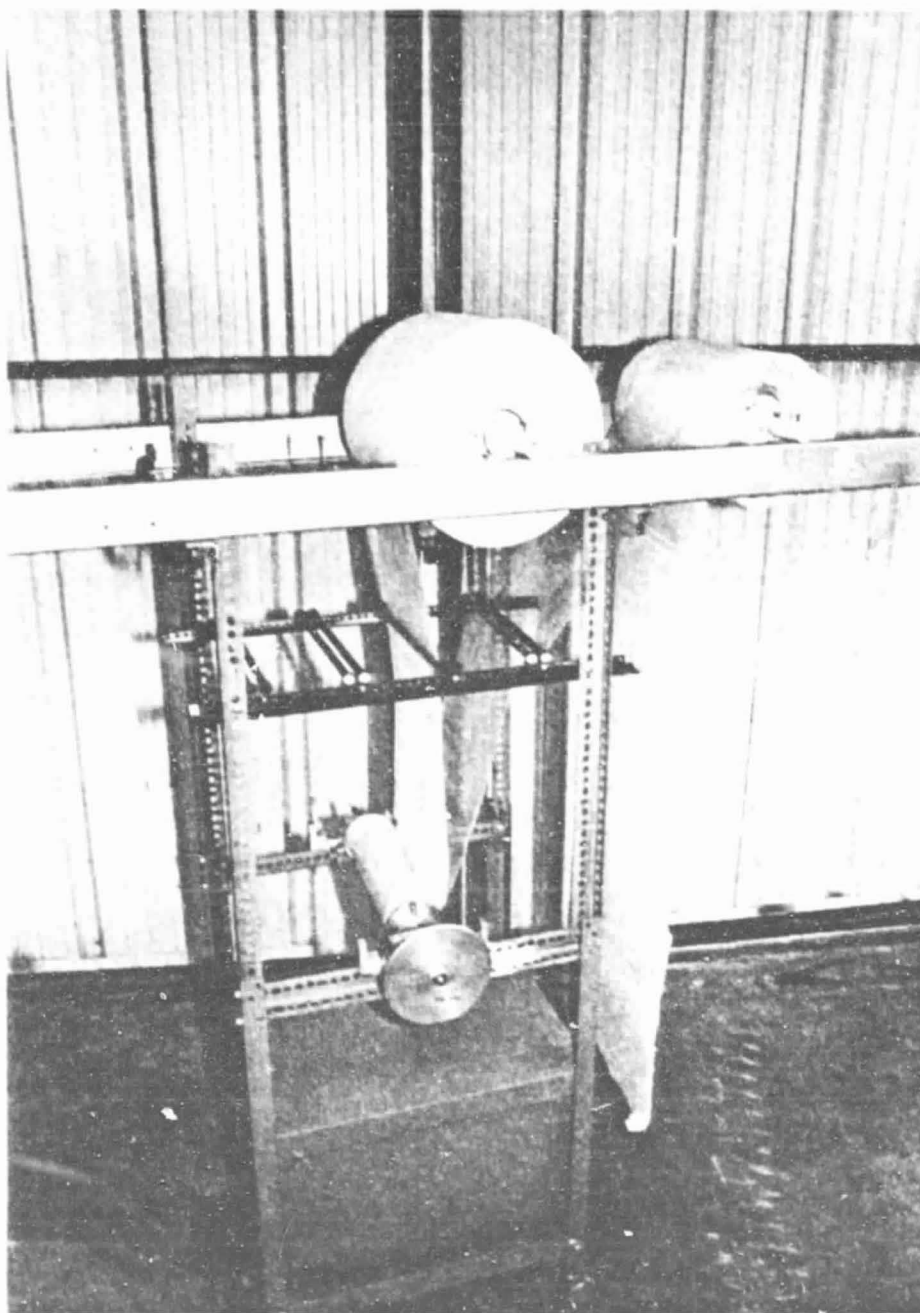
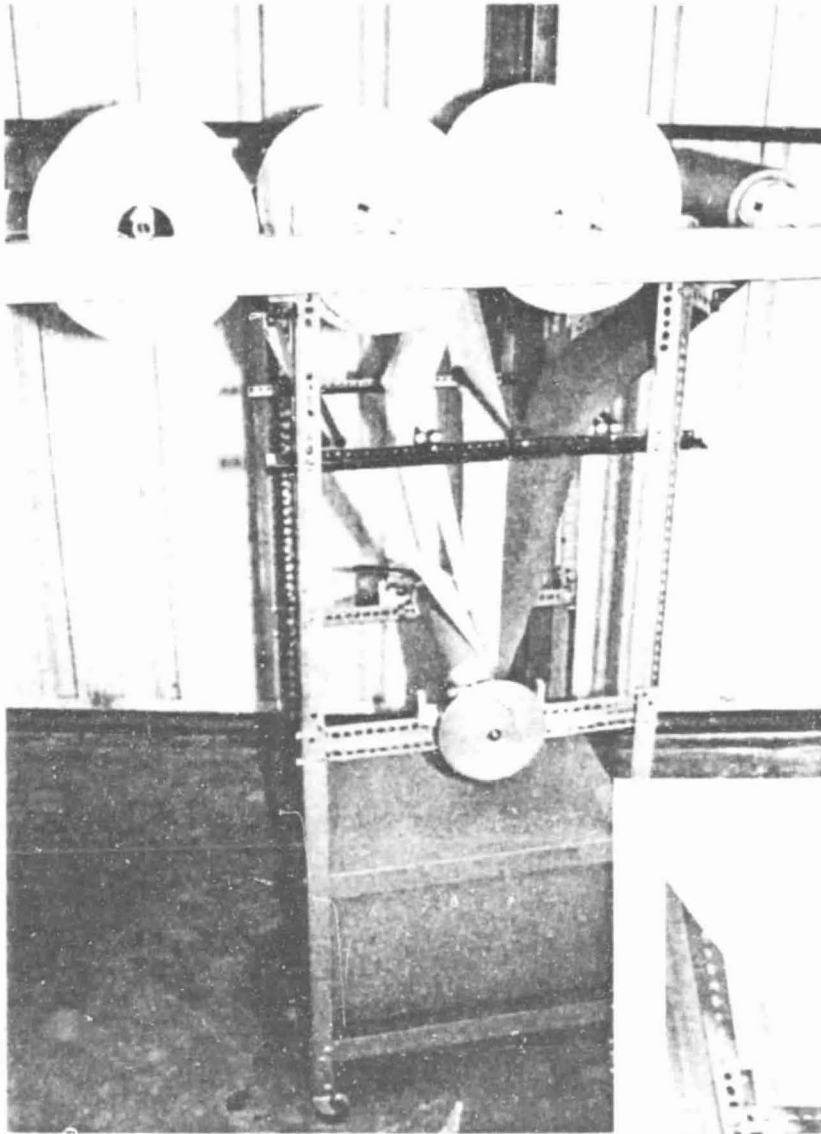


FIGURE 6  
MULTI-PLY ROLLER: TWO PLY

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FIGURE 7  
MULTI-PLY ROLLER, FOUR PLY

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will have to be determined by experience. Our suspicion is that the necessary tensions will be much lower.

To maintain this tension in a controlled manner, the web passes over a dancer roller which is located between the supply spool and the feed rollers (Figure 8, left). The dancer roller (so named because it appears to "dance" on the web during operation) is mounted on a vertical, pivoted arm (Figure 8, right) and performs several important functions of web control. First, the arm is spring loaded which applies the control tension to the web. Second, the position of the arm is used as feedback by the supply spool brake to maintain a constant web tension which it does in the following manner: If the web tension were to drop, the arm would pivot forward in the direction of the spring load. This motion applies the brake more increasing the web tension. Conversely, if the web tension were to rise, the arm would pivot back against the spring load releasing the brake some and thus lowering the web tension. It should be mentioned here that the brake is of the external compression strap type (similar to the "Rocky Mountain" brakes of early automobiles) with a  $270^{\circ}$  wrap of brake lining around the drum. We have designed it to be self de-energizing which, although requiring greater activation forces, is a very smooth and progressive brake inherently free from chatter and lockup.

The final function of the dancer arm is to provide web storage during start-up and shut-down of the shuttle. The shuttle comes up to speed very quickly (a few milliseconds) and since some material is stored in the dancer loop, the only part of the web that must be accelerated with the shuttle is the length between it and the dancer roller. The mass of this small length is insignificant compared to that of the shuttle itself. After the shuttle starts, the web tension rises very quickly exceeding the desired level. To compensate the dancer arm moves the brake to the full off position which allows the supply spool to accelerate unimpeded. As the spool unwind speed approaches the shuttle's speed, the dancer moves forward gradually applying the brake until the correct web tension is reached. Since the shuttle's acceleration is rigidly defined by the stepper motor, we selected the other web tension design parameters (dancer pivot length, brake diameter, spring preloads, etc.) to allow a full, 1.2" diameter supply spool to come up to speed in a few tenths of a second; a two-order-of-magnitude reduction

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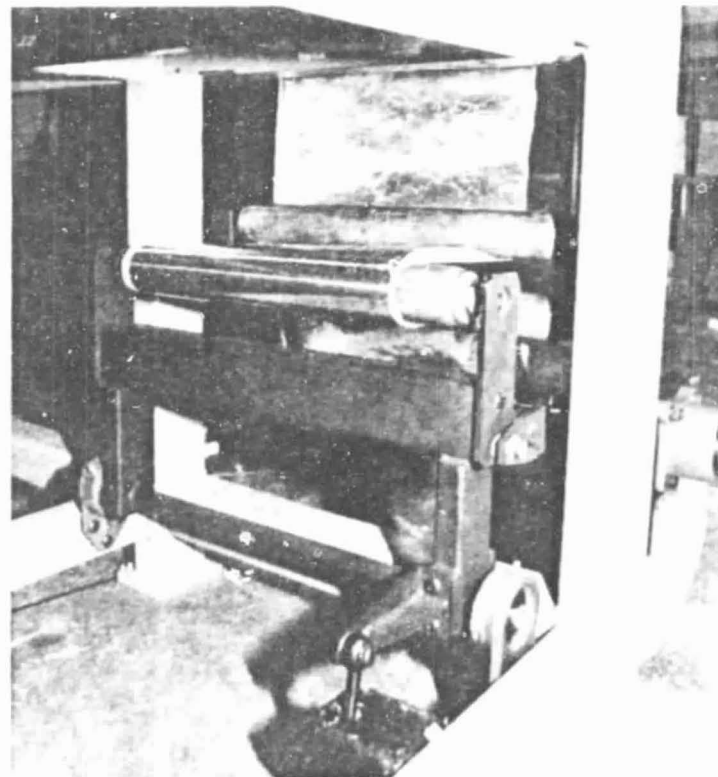
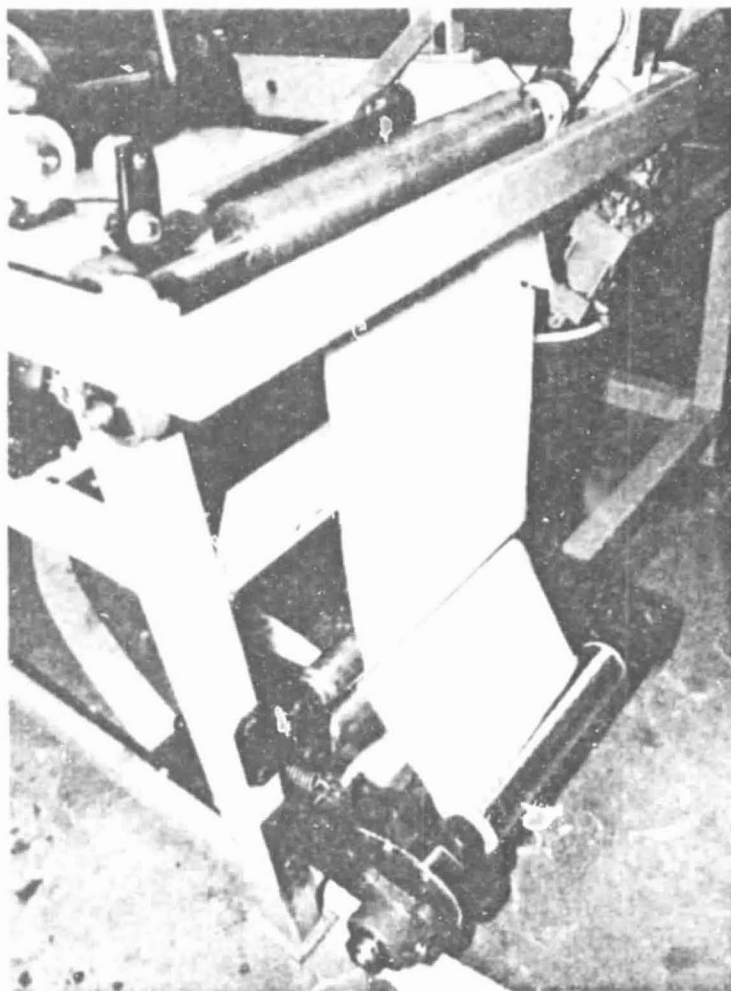


FIGURE 8  
WEB TENSION CONTROL

over a directly attached shuttle and spool.

When stopping the shuttle, the opposite happens. The shuttle stops in, again, a few milliseconds but inertia causes the supply spool to continue unwinding. The web tension thus drops very quickly and the dancer moves all the way forward applying the brake fully. This stops the spool and the material stored by the dancer during the stop is used for the next start.

The first test of the web feeding system used a hand-rolled 4-ply supply roll of mylar coated aluminum foil, Craneglas, white EVA, Craneglas (this roll is seen in Figures 4 and 8). The web tension was far too high (an estimated 60-70 lbs.) due to too much brake force. We are currently resizing the springs that apply the preload to the brake to get the web tension down to the desired 20-30 lbs. However, if our suspicions of very low web tension requirements are correct, the brake may not be required at all. The friction of the web passing over the three rollers may be sufficient. If so (we won't find out until the new shuttle drive motor is installed), then the brake will be eliminated and the dancer arm refitted with very light springs to perform only the start-up/shut-down storage function.

## 2.2

### Automated Lamination Chamber

The Automated Lamination Chamber is a very shallow vacuum chamber based on the vacuum bag principle which contains a heat source for curing the encapsulants. The actual chamber is a piece of aluminum sheet with 1" diameter aluminum tubing welded around the edge like a picture frame. The tubing plays the dual role of being the chamber sides and vacuum manifold. Small holes drilled into the tubing form the vacuum inlets. The cover is a sheet of soft silicone rubber as per the vacuum bag principle. For opening and closing, the cover is attached to longitudinal supports that allow it to be rolled up like a roll top desk lid.

The chamber sits on a box-like framework which both improves its torsional rigidity and provides an area to mount the cover opening mechanism, vacuum control solenoid, ribbon heaters and all attendant wiring and plumbing.

The vacuum chamber has undergone a minor redesign and rebuild since the description in previous reports. Specifically, the aluminum plate forming the chamber bottom has been increased in thickness from 0.090" to 0.125". Also, the 1" OD tubing surrounding the plate has been changed from thinwall to thickwall. Both of these changes were made to improve the rigidity of the chamber as the previous design warped severely during construction when welded.

Another change has to do with the chamber cover mechanism. The constant force springs previously used to aid in closing the cover have been replaced by Berg chain\*. There is now a continuous loop of chain so that the cover is opened and closed in much the same manner as a curtain rod.

The 1/8" thick silicone rubber sheet originally used to form the chamber cover proved to be too stiff to make a good seal when the chamber was first pumped down, even with extensive clamping around the edge. Since the chamber must be self sealing with no help from clamps or other aids, a three-pronged solution to the problem was devised. First, the top (sealing) surface of the "picture frame" tubing was fly cut to both increase the available surface area and to ensure a uniform sealing surface. Second, the rubber sheet was reduced to 1/16" thick to help it conform to the chamber's shape. Lastly, the new sheet was of a softer compound (40 Duro-meter instead of 50) to aid in its flexibility.

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\* A light-weight industrial chain consisting of small diameter stainless steel cables with high strength plastic rollers. It is a very flexible chain (both literally and figuratively) allowing great latitude in design.



This solution worked well enough to cause another minor problem. With the new rubber sheet simply lying on top of the chamber (i.e. with no clamping or any other aids) when the vacuum was applied, the sheet would be sucked down conforming to the various shapes of chamber and module, much like a vacuum forming process. In fact, it conformed so well that the sheet was pulled into the gap between the module and frame tube cutting off the vacuum to the module! The solution to this was to cut shallow slots (1/16" deep) in the floor of the chamber from a point underneath the module over to the vacuum hole in the frame tube. In this way, even if the sheet is sucked completely to the floor of the chamber, it won't be able to conform to the sharp edges of the slot and the vacuum path to the module will remain unrestricted.

Other work on the chamber involves the installation of the heat and instrumentation equipment. The heat tape (see Quarterly Report #1, Section 2.3.3.1) has been attached in a pattern that should result in a controlled and uniform application of heat. Some experiments will be done to help optimize the pattern. Ten thermistors have been installed in the chamber floor (one in each corner, one along each side and two in the center). Although only four will be used at a time (one corner, long side, short side and center) the others are there as backup in case of damage since the thermistors are epoxied into place and would be very difficult and time consuming to remove and replace. A vacuum transducer has also been installed to sense the vacuum level in the manifold to allow a controlled pump down of the chamber.

### 2.3 Edge Seal and Final Assembly

Work on this machine began with a design review meeting. Since this meeting the final configuration has been determined, most of the machine drawings are completed, and construction has begun.

The requirements of this machine are the same as noted in Quarterly Report #1, Section 2.4.

The goal of this phase is to take the encapsulated modules, such as would be removed from the lamination chamber at the end of its

cycle, and turn them into field-installable solar panels.

This requires, at the minimum, edge sealing, framing, and the attachment of (or installment into) a field support structure.

Our approach is to use MBA's Glass Reinforced Concrete (GRC) as a combination substrate, edge frame and support structure. The 4'x8' (GRC) panel design was developed by MBA for JPL under contract #955281.

The GRC panel has a 1/4" deep indentation on the surface which acts as an edge frame and allows the module's glass surface to be flush with the panel's concrete edge.

The edge seal (a hot melt Butyl) is applied by a machine that has controlled rectilinear motion.

#### 2.3.1 Sequence of Operations

The general sequence of operations for the edge seal machine (which has eight 1'x4' modules per GRC panel) is:

- 1) The edge sealant is applied along the three sides of the GRC panel where the edges of module #1 will make contact.
- 2) Module #1 is placed into the GRC panel by the robot.
- 3) Edge sealant is applied to the panel where the two short sides of module #2 will make contact and along the fourth side of module #1 where the two modules join.
- 4) Module #2 is placed into the GRC panel by the robot.
- 5) Steps 3 and 4 are repeated five times for modules 3 thru 7.
- 6) Edge sealant is applied to all four sides of the remaining opening in the GRC panel.

- 7) Module #8 is placed into the GRC panel by the robot.
- 8) The panel is removed for attachment of electrical hardware followed by packing and shipping to the installation site.
- 9) A new (empty) GRC panel is put in place and the cycle starts over.

The cycle time of the Edge Seal machine would be tied to that of the encapsulation station, i.e., approximately one minute per module or eight minutes for a 4'x8' panel.

It should be noted that while a 4'x8' panel is the maximum size that the machine can process, there is no limit to either the minimum size or gradation of the sizes. Being driven by stepper motors controlled by an interactive computer, the machine can handle any size or shape panel within the resolution of the steppers (approximately 0.05" at present gearing). Of course, rectangular panels are better suited as the control system's digital nature may become apparent if it tries to follow odd angles or compound curves.

### 2.3.2 Edge Seal Machine Progress

The concept of an X-Y applicator was retained for the edge seal machine (Quarterly Report No. 1, Figure 14). The machine is composed of three components; shuttle, carriage, and frame. An explanation and description of these components is listed below.

#### 2.3.2.1 Shuttle

It is easy to see from Figure 9 that the shuttle is ninety percent built. The purpose of the shuttle is to hold the hot melt applicator secure while moving in a controlled rectilinear motion. The shuttle is powered by a horizontally mounted motor, and "crawls" by using a sprocket and chain arrangement. To allow for misalignment of the carriage tracks, fixed rollers were used on one side of the shuttle and floating rollers on the opposite side. The shuttle moves along the X axis\* while the hot melt is being applied.

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\* X axis applies to the 4' length of the CRC Panel, Y axis is the 8' length.

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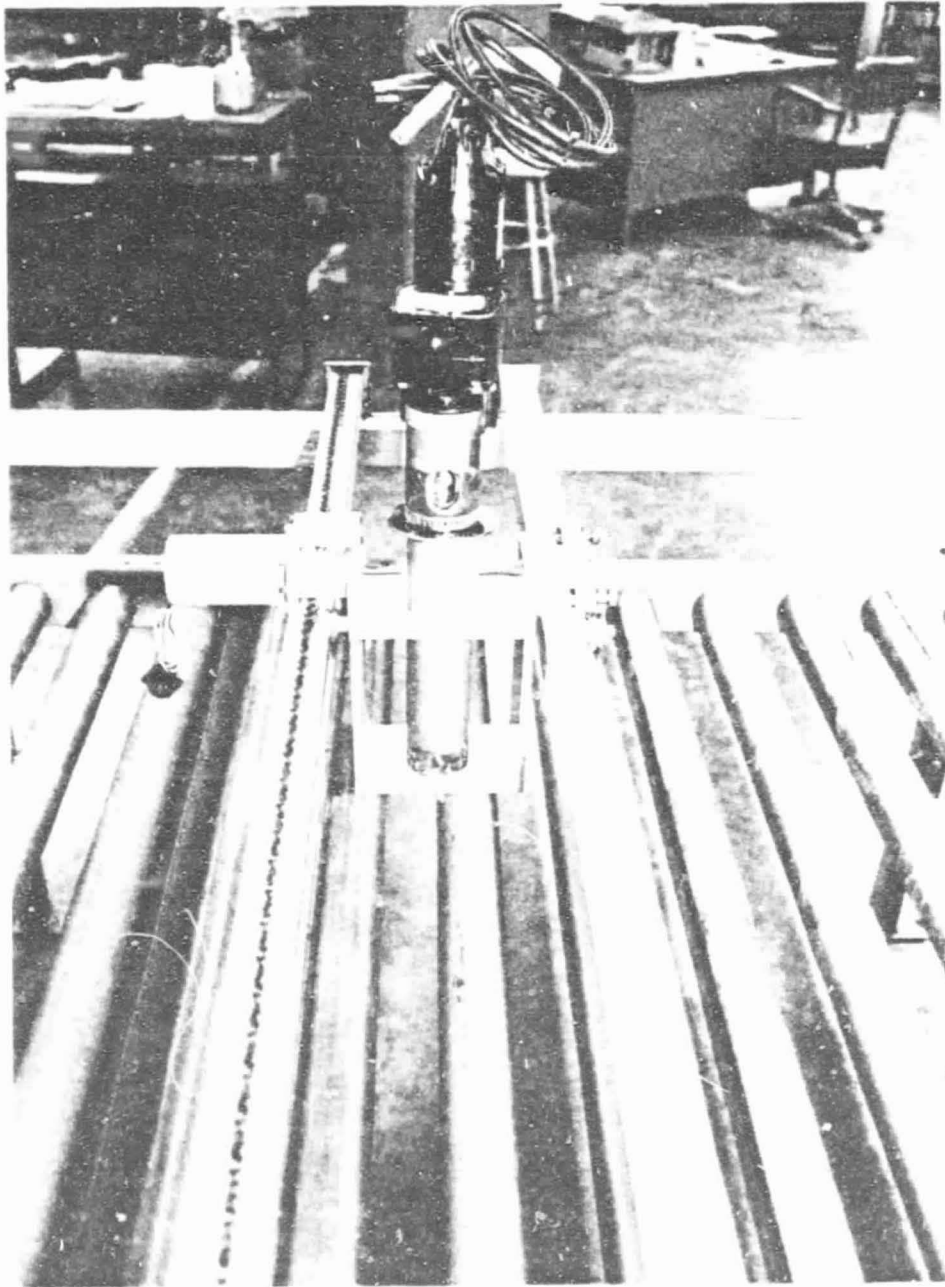


FIGURE 9  
HOT MELT GUN IN SHUTTLE

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#### 2.3.2.2 Carriage

The carriage is the support upon which the shuttle rolls. The carriage itself, in turn, is also mounted on rollers which move along the frame perpendicular to the shuttle. Figure 10 shows the carriage sitting in position on the frame with the shuttle, in turn, on it. The end plates, drive shaft, and other remaining parts of carriage are either on order or are being constructed. The purpose of the carriage, then, is to support the shuttle while it moves along the X axis (on top of the carriage) and also to move the shuttle along the Y axis\* on top of the frame. The carriage will also "crawl" by using a sprocket and chain arrangement (although it is driven at both ends via the drive shaft) and will also have floating rollers on one end to allow for misalignment of the frame. The chain that both the shuttle and carriage "crawl" on is Berg chain, identical to that described in Section 2.3.

#### 2.3.2.3 Frame

The frame is the support on which the carriage travels back and forth. The frame has no mechanical moving parts (other than the unpowered conveyor rollers) and is already ninety percent complete.

Since the Edge Seal machine was designed to apply a hot melt to either a single encapsulated module or multiple modules (up to eight 1'x4') while the module is resting on top of a GRC panel, the simplicity of inserting and removing GRC panels had to be considered. A standard industrial roller conveyor was decided upon to roll GRC panels into position and provide the basic frame for the rest of the machine.

#### 2.4 Electronics

The electronics to control both the Lamination Station and Edge Sealing machine are basically identical as those that control the previous cell preparation station. They consist of an interface board which converts the computer's output data into discreet on/off commands, a high current drive board which amplifies these low level commands to operate solenoid valves and stepper motors and finally, an isolator board which

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\* X axis applies to the 4' length of the GRC Panel, Y axis is the 8' length.

Tracor MBA

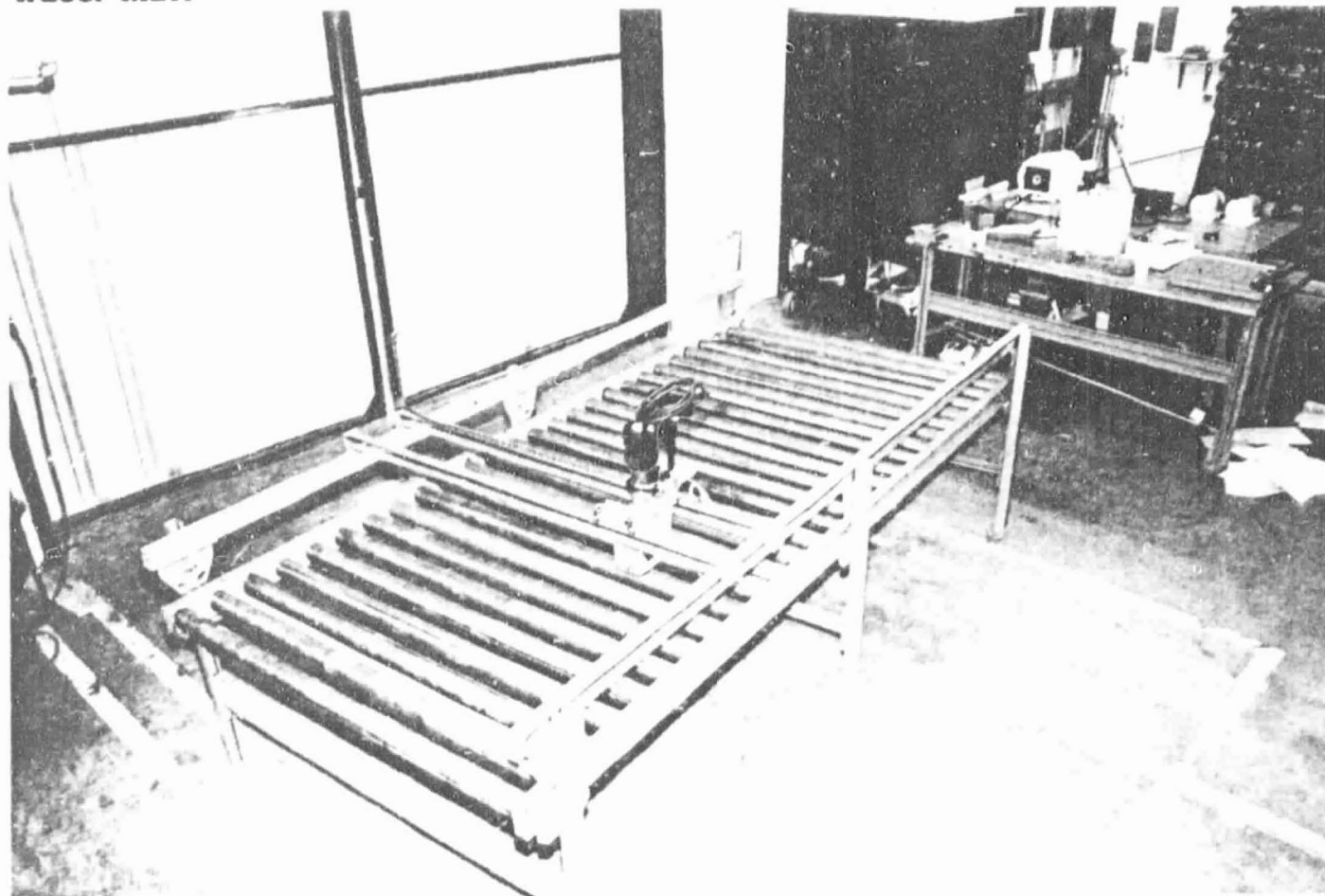


FIGURE 10  
FINAL ASSEMBLY STATION

is placed between the other two to protect the delicate interface board from any high current surges. The interface board also contains small reed relays to interface with the Unimate robot. All of this equipment is finished and either installed or waiting to be installed.

Since the requirements for this equipment are identical for both new machines, and since they will never be operated at the same time; as a matter of economy and expediency, we will be using the same set of electronics for both machines. Quick disconnect connectors are being used so that the cables can be easily switched. In a production situation, of course, each machine would have its own controller and even in our case separate computer programs for the two machines are required.

There are some additional electronics involved with these two new machines to handle requirements not encountered with the original cell stringing system. First is the ability to handle AC line voltage at high current. On the Laminator, this is necessary to run the heat ribbons and chamber open/close motor. On the Edge Sealing machine, both the hot melt heater and feed motor (not to be confused with the shuttle and carriage drive motors which are DC steppers) run on AC. This requirement is met by high current mechanical relays with 12v DC coils which allow them to be operated by the existing driver transistors.

The other new requirement pertains to the Lamination Station only, specifically the vacuum chamber. The chamber has many analog sensing elements (thermistors and a vacuum transducer as detailed in Section 2.3) whose signals must be converted to digital to be understood by the computer. Rather than hooking up each sensor to its own A to D convertor (which are quite expensive) we are using a multiplexer to scan the sensors on a time sharing basis. The multiplexer we are using (a Motorola 14051) can handle up to 8 inputs at one time and output them to a single A to D convertor in a controlled fashion.

The progress of this section of the electronics is somewhat behind the others mainly because the design requirements could not be determined until the chamber construction was nearly complete and its requirements fully understood.

### 3.0 CONCLUSIONS AND FUTURE WORK

The construction phase of the Automated Lamination Station has been completed. The electronic systems are about 90% complete with the instrumentation circuitry the last to be completed. Over the next quarter, we will be installing this, plus doing testing on both the single function and integrated system level.

The Final Assembly Station is progressing rapidly being out of the design phase and into construction. It can be considered over 50% complete and, since it shares its control systems with the Lamination Station, the electronics are ahead of the mechanical, for a change.

Both the Lamination Station and the Final Assembly Station will be on display at the 18th PIM in Pasadena next July for the inspection and critique of other LSA contractors.

### 4.0 PROGRAM PLAN

Included is a program plan that shows progress-to-date on the various phases as well as their projected completion dates.



